Climate Variability in Ocean Surface Turbulent Fluxes

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Project Summary

FSU produces fields of surface turbulent air-sea fluxes and the flux related variables (winds, SST, near surface air temperature, near surface humidity, and surface pressure) for use in global climate studies. Surface fluxes are by definition rates of exchange, per unit surface area, between the ocean and the atmosphere. Stress is the flux of horizontal momentum (imparted by the wind on the ocean). The evaporative moisture flux would be the rate, per unit area, at which moisture is transferred from the ocean to the air. The latent heat flux (LHF) is related to the moisture flux: it is the rate (per unit area) at which energy associated with the phase change of water is transferred from the ocean to the atmosphere. Similarly, the sensible heat flux (SHF) is the rate at which thermal energy (associated with heating, but without a phase change) is transferred from the ocean to the atmosphere. In the tropics, the latent heat flux is typically an order of magnitude greater than the sensible heat flux; however, in polar regions the SHF can dominate.

The FSU activity is motivated by a need to better understand interactions between the ocean and atmosphere on weekly to interdecadal time scales. Air-sea exchanges (fluxes) are sensitive indicators of changes in the climate, with links to floods and droughts[1] and East Coast storm intensity and storm tracks[2]. On smaller spatial and temporal scales they can be related to the storm surge, and tropical storm intensity. On longer temporal scales, several well-known climate variations (e.g., El Nino/Southern Oscillation (ENSO); North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO)) have been identified as having direct impact on the U.S. economy and its citizens. Improved predictions of ENSO phase and associated impact on regional weather patterns could be extremely useful to the agricultural community. Agricultural decisions in the southeast U.S. sector based on ENSO predictions could benefit the U.S. economy by over $100 million annually[3]. A similar, more recent estimate for the entire U.S. agricultural production suggests economic value of non-perfect ENSO predictions to be over $240 million annually[4]. These impacts could easily be extended to other economic sectors, adding further economic value. Moreover, similar economic value could be foreseen in other world economies, making the present study valuable to the global meteorological community.

ENSO, PDO, and NAO (AO) each have atmospheric and oceanic components that are linked through the surface of the ocean. Changes in the upper ocean circulation result in modifications to the SST and near surface wind patterns. Variations in SSTs can be related to ENSO and other

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[1] Enfield, D. B., A. M. Metas-Nuñez, and P. J. Trimble, 2001: The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental U.S. *Geophy. Res. Let.*, **28**, 2077-2080.

[2] Hurrell, J.W., and R.R. Dickson, 2004: Climate variability over the North Atlantic. Marine Ecosystems and Climate Variation - the North Atlantic. N.C. Stenseth, G. Ottersen, J.W. Hurrell, and A. Belgrano, Eds. Oxford University Press, 2004.

[3] Adams, R. M., K. J. Bryant, B. A. McCarl, D. M. Legler, J. O'Brien, A. Solow, and R. Weiler, 1995: Value of improved long-range weather information. *Contemporary Economic Policy*, **13**, 10-19.

[4] Solow, A. R., R. F. Adams, K. J. Bryant, D. M. Legler, J. J. O'Brien, B. A. McCarl, W. Nayda, and R. Weiler, 1998: The value of improved ENSO prediction to U. S. agriculture. *Climate Change*, **39**, 47-60.

climate patterns; however, it is the fluxes of heat and radiation near the ocean surface that transfer energy across the air-sea interface. It is an improved understanding of these turbulent fluxes and their variability that motivates our research (radiative fluxes are difficult to accurately estimate from in situ data; however, satellite-based estimates are available). By constructing high quality fields of surface fluxes we provide the research community the improved capabilities to investigate the energy exchange at the ocean surface.

FSU produces both monthly in-situ based (the FSU3) and hybrid satellite/numerical weather prediction (NWP) fields of fluxes and the flux-related variables. Our long-term monthly fields are well suited for seasonal to decadal studies, and our hybrid satellite/NWP fields are ideal for daily to annual variability and quality assessment of the monthly products. The flux-related variables are useful for ocean forcing in models, testing coupled ocean/atmospheric models, and for understanding climate related variability (e,g., the monthly Atlantic surface pressure is a good indicator of extreme monthly air temperatures over Florida).

The flux project at FSU targets the data assimilation milestones within the Program Plan. Our assimilation efforts combine ocean surface data from multiple Ocean Observing System networks (e.g., VOS, moored and drifting buoys, and satellites). One set of performance measures targeted in the Program Plan is the air-sea exchange of heat, momentum, and fresh water. When the FSU products are combined with ocean models (either at FSU or other institutes), performance measures relating to surface circulation and ocean transports can be addressed. The FSU flux project also focuses on the task of evaluating operational assimilation systems (e.g., NCEP and ECMWF reanalyses) and continues to provide timely data products that are used for a wide range of ENSO forecast systems. All products are distributed in a free and open manner at: http://www.coaps.fsu.edu/RVSMDC/FSUFluxes/.

Accomplishments

Over the past year our focus has deviated from our stated deliverable for FY 2007. The air-sea flux community has produced a number of in-situ, satellite, model-based flux products and there has been great interest in determining how the products compare. An analysis of nine flux products (including the FSU Fluxes) has been completed, and it has revealed a vast difference between these products. We began production of research-quality, in-situ monthly flux fields for the tropical and north Pacific Ocean. During this process, we identified some problems that result in unrealistic fields around the TAO moorings (a similar problem was identified in many of the comparison products). The product release has been delayed until we can modify our analysis to remove this feature. We also continued our operational production of monthly quick-look wind fields for the tropical Pacific and Indian Oceans.

Global and Regional satellite stress products have continued to improve through more effective use of rain-flagged (suspect) observations. We now eliminate far less suspect data, and have more physically consistent fields around tropical cyclones. We have also developed a preliminary technique for the direct calculation of stress from scatterometer backscatter. This approach should address several issues that could result in substantial regional biases in our stress products.

Deliverables for FY 2007 included:

1. Update Atlantic, Indian, and Pacific Oceans using new ICOADS releases (if available)

2. Complete Equatorial and North Pacific 1˚ winds and fluxes
3. Begin operational production and distribution of quick-look, 1˚ in situ fluxes for the Atlantic, Indian, and Pacific Oceans
4. Extend the Atlantic Ocean fluxes back in time from 1978
5. Continue comparisons of FSU winds and fluxes to other available in-situ, satellite, and blended flux products
    - Subtask1: Add GODAS fluxes to comparison
6. Objective estimation of uncertainty in flux fields and related variables
    - Subtask1: First complete uncertainties for wind vector components
7. Production of satellite and NWP hybrid fluxes.
    - Subtask1: Estimate biases in NWP near surface temperatures and humidities

Update products using new ICOADS releases [Deliverable 1]

No updates for ICOADS were made available in FY 2007; therefore, we did not complete any updates or extensions to our products past 2004. We anticipate an ICOADS update to be released in 2008, so this task will be pushed forward.

Complete Equatorial and North Pacific 1˚ in-situ fluxes [Deliverable 2]

In FY 2007, we completed the automated and visual data quality evaluation for the tropical and North Pacific Ocean fluxes for the period 1990-2004. The 1˚ wind and flux products (the FSU3) for the Pacific Ocean revealed a problem with our handling of moored buoys (especially in the tropics) which resulted in the mooring chains being evident in the objective flux fields (Figure 1). We are beginning to test several solutions to this problem, and will implement the successful combination in FY 2008. The problem is due to the sparse longitudinal sampling of the TAO buoys, and to small but widespread and seasonally varying biases relative to the ship observations. We also found that many ship observations had been misclassified (in ICOADS) as moored buoys. We have developed an automated technique for removing the vast majority of such misclassified data, and are in the process of investigating the impacts on our products.

Production of in-situ quick-look products [Deliverable 3]

Although we were unable to implement quick-look versions of the 1˚ objective FSU fluxes, we continue to create an older version (the FSU2) 2˚ tropical Pacific Ocean wind (pseudo-stress) fields based on near-real time in-situ data. Quick-look 2˚ gridded pseudo-stress fields are produced at the beginning of each month using the previous month's GTS-transmitted data. In addition to the Pacific, COAPS continues to produce one-degree pseudo-stress fields for the tropical Indian Ocean using the method of Legler et al.[5]. Related research quality products exist through 2004 for the Pacific and 2003 for the Indian Ocean. We have not updated the FSU2 and Legler research products as we had anticipated switching to the Bourassa 3.0 method. This switch was delayed by the desire of the flux community to have an assessment of multiple flux products (including the FSU3). We also must solve the problem with the mooring data revealed while creating the FSU3 for the tropical Pacific (figure 1). We will push the quick-look FSU3 product forward to FY 2008. Both two-degree fields for the Pacific Ocean and one-degree fields

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[5] Legler, D. M, I. M. Navon, and J.J. O'Brien, 1989: Objective analysis of pseudostress over the Indian Ocean using a direct-minimization approach. *Mon. Wea. Rev*., **117,** 709-720.

for the Indian Ocean FSU winds are available at http://www.coaps.fsu.edu/RVSMDC/SAC/index.shtml.

As part of our continued production of the FSU2 for the tropical Pacific Ocean, we now produce additional monthly graphics for inclusion into the on-line version of the NOAA Climate Diagnostics Bulletin (http://www.cpc.ncep.noaa.gov/products/CDB/).

Extend the Atlantic Ocean fluxes back in time from 1978 [Deliverable 4]

This activity was delayed due to the need for a detailed comparison of available monthly flux products. Due to flat budgets in recent years and shifting priorities in the air-sea flux community, this deliverable has been removed from our FY 2008 work plan. When sufficient resources can be obtained (either via add tasks or other agency funding), we will extend our series back prior to 1978.

Continue comparisons of FSU winds and fluxes to available products [Deliverable 5]

As mentioned above, a detailed comparison of the FSU3 to other freely available air-sea flux products was a priority for FY 2007. We found large differences in scalar wind speed, humidity, and heat fluxes. Examples of these differences are apparent in the zonal quantiles for the Indian and Atlantic Oceans (Figure 2). The magnitude of the LHF differences can reach 80 Wm^{-2} at some latitudes. The magnitude of the differences varies at different quantiles. Examining the quantiles shows additional variability in the spread of the LHF distribution between the nine flux products. We also found substantial differences in the curl and divergence of these products, which are important considerations for ocean forcing (curl) and cloud processes (divergence). In many cases, the observing system (and numerical ring from the NCEP1 product) was easily identified in the derivative fields. This finding indicates serious problems in using these products to force ocean models. We also found that the differences in products were more than offsets and proportionalities: there were very large differences in statistical distributions of the data, which would again be important for ocean forcing. This activity will be ongoing.

Objective estimation of uncertainty in flux fields and related variables [Deliverable 6]

We have made little progress on this task. We have coded the necessary calculations (which are extremely complex), but are still in the process of debugging. This task will be continued in 2008.

Production of satellite and NWP hybrid fluxes. [Deliverable 7]

We produce equivalent neutral pseudostress fields, which can easily be used to determine surface stress. For isolated projects we produce hybrid NWP and satellite fluxes; however, we believe that there are substantial errors in the heat fluxes that should be addressed prior to public release of these products. This task will be continued in 2008.

Publications and Reports

Refereed

Arguez, A., J. J. O'Brien, and S. R. Smith, 2007: Air Temperature Impacts over Eastern North America and Europe Associated with North Atlantic SST Variability. *Int. J. Climatol.*, submitted.

Hughes, P. J., M. A. Bourassa, J. J. Rolph, and S. R. Smith, 2007: Tropical Atlantic flux variability. *J. Atmos. Ocean. Technol.*, in preparation.

Kara, A. B., A. J. Wallcraft, C. N. Barron, E. J. Metzger, H. E. Hurlburt and M. A. Bourassa, 2007: Accuracy of 10 m Wind Speeds from Satellites and NWP Products Near Land–Sea Boundaries, *J. Geophys. Res.*, submitted.

Kennedy, A. J., M. L. Griffin, S. L. Morey, S. R. Smith, and J. J. O'Brien, 2007: Effects of El Niño-Southern Oscillation on sea-level anomalies along the Gulf of Mexico coast. *J. Geophys. Res.*, **112**, C05047, doi:10.1029/2006JC003904.

Morey, S. L., D. S. Dukhovskoy, and M. A. Bourassa, 2007: Connectivity between variability of the Apalachicola River flow and the biophysical oceanic properties of the northern West Florida Shelf. *Continental Shelf Research*, submitted.

Rolph, J. J., R. Banks, M. A. Bourassa, and S. R. Smith, 2007: Indian Ocean flux variability. *J. Climate*, submitted.

Smith, S. R., C. Tartaglione, J. J. O'Brien, and J. Brolley, 2007: ENSO's impact on regional U.S. hurricane activity. *J. Climate*, **20**, 1404-1414.

Technical reports and other publications

Bourassa, M. A., D. Dukhovskoy, S. L. Morey, and J, J. O'Brien, 2007: Innovations in Modeling Gulf of Mexico Surface Turbulent Fluxes. Flux News, Issue 3, World Meteorologica1 Organization, eds. Bernard Barnier and Sergey Gulev, 9.

Bourassa, M. A, R. N. Maue, S. R. Smith, P. J. Hughes, and J. Rolph, 2007: Global winds. *State of the Climate in 2006*. A. Arguez, H. J. Diamond, F. Fetterer, A. Horvitz, and J. M. Levy, Eds., *Bull. Amer. Meteor. Soc.*, 88, S25-S27.

Smith, S. R., A. Bentamy, and C. A. Clayson, 2006: SEAFLUX 3rd Workshop. FLUX NEWS, Newsletter of the WCRP Working Group on Surface Fluxes, WCRP, Issue 2. [Available from http://www.esrl.noaa.gov/psd/psd3/wgsf/].

Conference proceedings/presentations

Bourassa, M. A., and P. J. Hughes, 2006: Sensitivity of surface turbulent fluxes to errors in bulk formula inputs. *HYCOM NOPP GODAE* Meeting. Nov. Tallahassee, FL.

Bourassa, M. A., and S. R. Smith, 2007: Improving air-sea flux estimation with a new wave-dependant parameterization and high-quality research vessel observations. *ONR Progress Review – Southeast Region*, Tallahassee, FL.

Bourassa, M. A., P. J. Hughes, and S. R. Smith, 2006: Comparison of surface turbulent flux products, *Fall AGU Meeting*, Dec., CA.

Bourassa, M. A., P. J. Hughes, J. Rolph, and S. R. Smith, 2007: North Atlantic decadal variability of ocean surface fluxes. *7th Workshop on Decadal Climate Variability*, April, Waikoloa, HI.

Bourassa, M. A., P. J. Hughes, and S. R. Smith, 2007: Comparison of surface turbulent flux products. Joint , Sept., Amsterdam, Netherlands.

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Bourassa, M. A., Paul J. Hughes, Jeremy Rolph, and Shawn R. Smith, 2007: Hurricanes and Atlantic Surface Flux Variability. *NOAA Climate Observation Division 5th Annual System Review*, June, Silver Springs, MD.
Bourassa, M. A, J. Rolph, P. Hughes, and S. R. Smith, 2007: An update of the FSU3 Winds and Fluxes. *Climate Observation Division 5th Annual System Review*, Silver Spring, MD, USA, NOAA, in press.
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Hughes, P. J., and M. A. Bourassa, 2007: Variability of latent and sensible heat fluxes over the tropical Atlantic. *ONR Review*, May, Tallahassee, FL.
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Figures

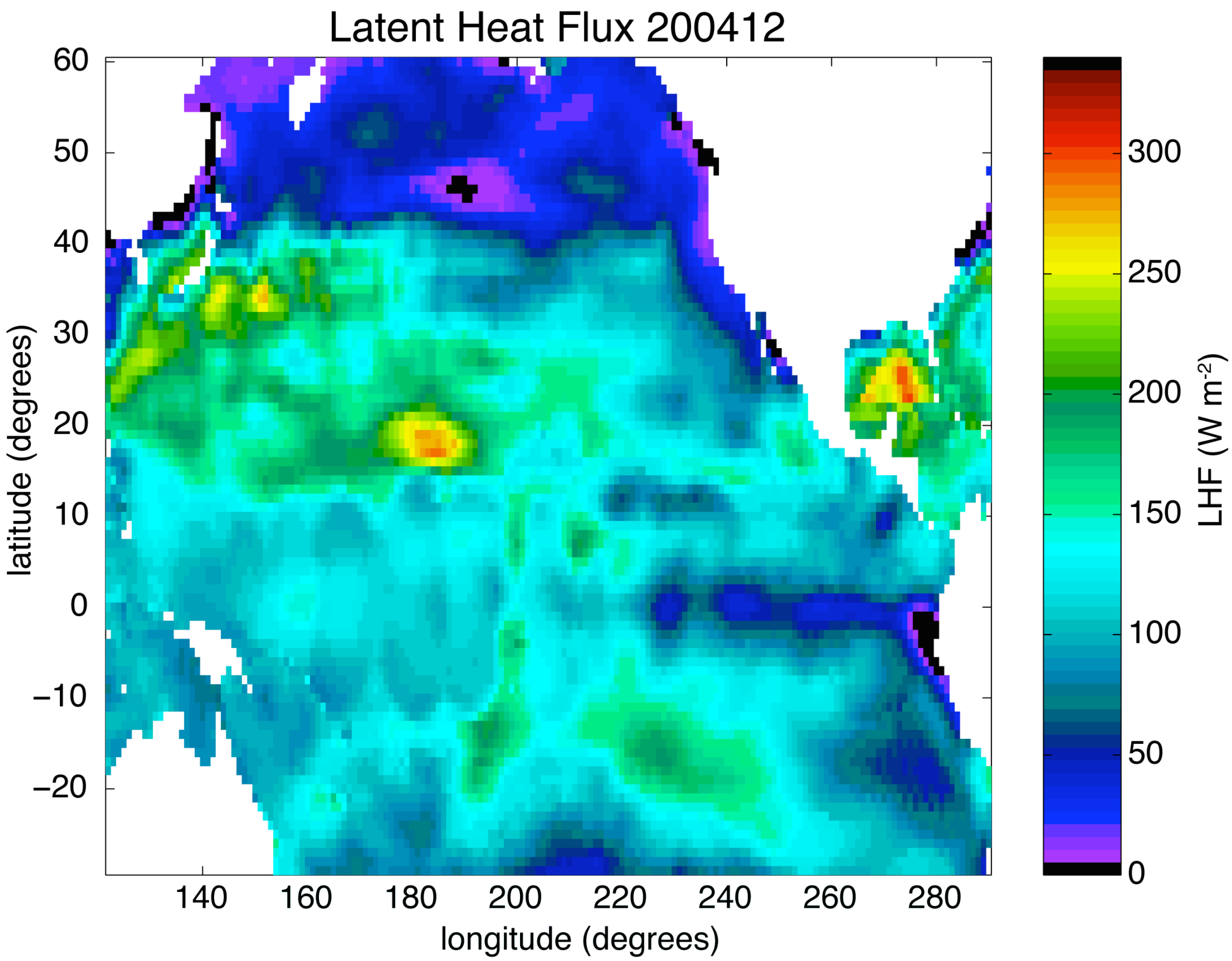

Figure 1. An example of the preliminary FSU3 latent heat flux field for December 2004. The elliptical patterns in the field along the equator are caused by the TAO moorings in the tropical Pacific. These artificial features will be removed through modifications to our objective gridding technique.

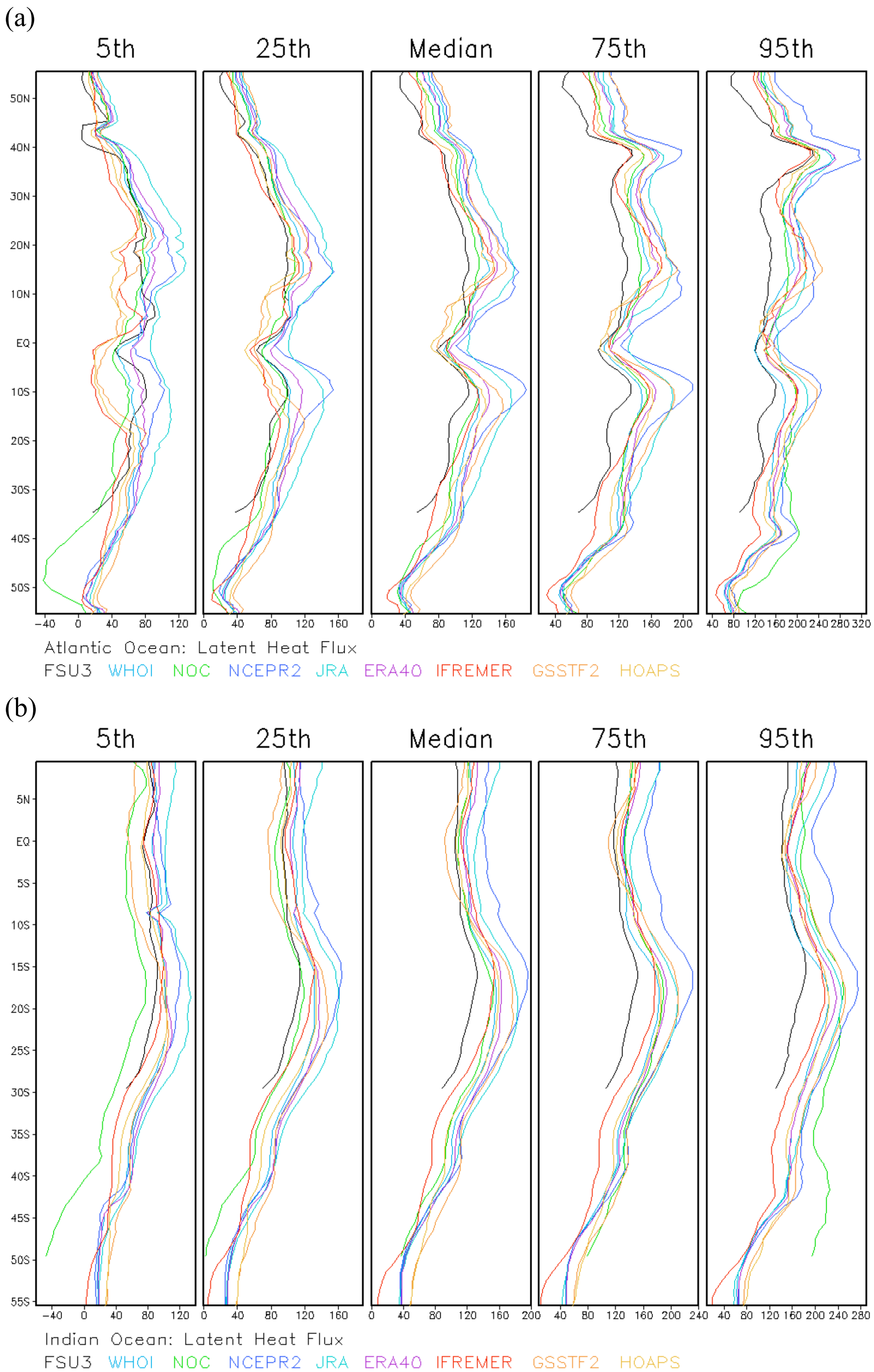

Figure 2. Zonal quantile values for latent heat flux for the (a) Atlantic and (b) Indian Oceans. Values are presented for nine flux products. All products are on a common 1˚ grid and use a common land mask. Substantial differences (upwards of 80 Wm^{-2}) exist between the products.